Cultivar Differences in Resistance to the Inhibitory Effects of Near-UV Radiation among Asian Ecotype and Japanese Lowland and Upland Cultivars of Rice (*Oryza sativa* L.)

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Cultivar differences in resistance to the inhibitory effects of near-ultraviolet (near-UV) radiation among 5 Asian rice ecotypes (*aus*, *aman*, *boro*, *bulu*, *tjereh*) and the Japanese lowland and upland rice groups (*Oryza sativa* L.) were examined. Experimental plants were grown under visible radiation supplemented with or without near-UV radiation containing a large amount of UV-B (ultraviolet radiation between 280 and 320 nm wavelength) and a small amount of UV-C (ultraviolet radiation less than 280 nm wavelength) in a phytotron. Prepared plots in this experiment were a "control", and "low", "medium" and "high" levels of irradiance of near-UV light.

The range of the frequency distributions of the ratios of fresh weight and plant height of the sample to those of the control under the "low" irradiance level was wide within each ecotype and group. Different sensitivities to the effects of near-UV radiation were involved in the same ecotype and the same group: one type was promoted by near-UV radiation i.e. "resistant" type, while the other type was inhibited i.e. "sensitive" type. With an increase in the irradiance level of near-UV radiation to the "medium" or "high" level, the growth of each cultivar was much more inhibited. However, it was noted that all the cultivars which showed strong resistance to the "low" irradiance level did not necessarily show strong resistance to the "medium" irradiance level: some cultivars showed the stronger resistance to the "medium" irradiance level than to the "low" irradiance level. The proportions of cultivars, which showed resistance to the "low" irradiance level, were 79, 69 and 68% for the *boro*, *aus* and *aman* ecotypes from Bengal, 57 and 58% for the *bulu* and *tjereh* ecotypes from Indonesia, 75 and 54% for the Japanese lowland and upland rice groups, respectively. Under the "medium" irradiance level, the number of resistant cultivars significantly decreased: the proportion of resistant cultivars of the Japanese lowland rice group and the *boro* ecotype were 21 and 14%, respectively, while those of others were below 4%.

It was thus confirmed that the Japanese lowland rice group and the *boro* ecotype were more resistant to the near-UV radiation.

KEY WORDS: *Oryza sativa*, *indica*, *japonica*, cultivar difference, near-UV injuries, resistance to near-UV radiation.

Introduction

During the last two decades, it has been argued that the expansion of the ultraviolet region of the spectrum (in particular UV-B radiation) due to the apparent depletion of stratospheric ozone influences living things. TERAMURA (1983) who reviewed the effects of UV-B radiation on growth and yield of agricultural crops indicated that sensitivity to UV-B radiation varied among species and cultivars, and that approximately 30% of about 40 species tested were resistant to UV-B, another 20% was extremely sensitive, and the remainder was characterized by an intermediate sensitivity.

Among crops, the effects of UV-B radiation on growth and yield of soybeans have been extensively studied. It was reported that UV-B radiation significantly reduced growth and pho-

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tosynthesis of soybean [*Glycine max* (L.) Merr.] cv. Bragg in a greenhouse (Vu *et al.* 1981). It was also reported that some of 19 soybean cultivars tested showed a marked difference in sensitivity to UV-B radiation in a growth chamber (Biggs *et al.* 1981), and that cv. Essex was found to be sensitive to it, while cv. Williams was tolerant to UV-B radiation (TERAMURA *et al.* 1990). Information about the effects of UV-B radiation on growth and yield of rice cultivars is few. TERAMURA *et al.* (1991) reported that 6 of 16 rice cultivars from 7 geographical regions showed a significant decrease in total biomass, while one cultivar showed a significant increase with UV-B radiation simulating 20% ozone depletion in greenhouses. SUGE *et al.* (1991) indicated that gibberellin biosynthesis was related to resistance to near-UV radiation in rice plants. We found that there were cultivar differences among cultivars in the degree of resistance to near-UV radiation in rice plants and indicated that the cultivar differences in resistance to the effects of near-UV radiation was either due to a lower sensitivity to near-UV radiation or to a greater ability to recover from the inhibitory effects of near-UV radiation through exposure to visible radiation (KUMAGAI and SATO 1992).

In our experiments, near-UV radiation with a large amount of UV-B and a small amount of UV-C were used instead of high quality UV-B radiation. Simulation of the amount of expansion in the UV-region due to the depletion of stratospheric ozone was not taken into account, because of the limitations of experimental apparatus and dependence of the inhibitory effects of near-UV radiation on recovering ability through exposure to visible light. However, cultivars showing resistance to the inhibitory effects of near-UV radiation were estimated to exhibit higher tolerance to high quality UV-B radiation too.

Materials and Methods

Forty-eight *aus*, 37 *aman* and 14 *boro* ecotype cultivars from the Bengal region, 28 *bulu* and 31 *tjereh* ecotype cultivars from Indonesia and 29 lowland (j.l.r.) and 11 upland (j.u.r.) Japanese rice cultivars were used as experimental materials. The *aus*, *aman*, *boro*, and *tjereh* ecotypes belong to *indica*, *bulu* ecotype belongs to the tropical *japonica*, and Japanese lowland and upland rice groups belong to the temperate *japonica* (UENO *et al.* 1990).

Seeds of each cultivar, soaked in water at 26°C for 3 days, were planted on plastic vats (300 × 600 × 35 mm) containing soil prepared for nursery bed (Mitsuitoatu Ltd. Co., Chiba, Japan). Seedlings were placed in a large growth chamber (Koito tron type KG: Koito Ind. Co., Tokyo, Japan). The soil in the plastic vat was watered every day to maintain a sufficient moisture.

Plastic vats in the growth chamber were moved every day so that the seedlings could receive an equal amount of light irradiation. The photoperiod consisted of 12 h of light and 12 h of dark and temperature was maintained at 25°C during day and 17°C at night. Various light treatments were initiated when seedlings had reached the three leaf stage and plants were grown for further 20 days. Prepared experimental plots were a "control" and three levels of irradiance of near-UV light, i.e. "low", "medium" and "high". Each irradiance (W/m²) in the region of UV-B and UV-C was 0.01 and non-detectable (ND) for the "control"; 0.06 and 0.009 for the "low" level; 0.12 and 0.018 for the "medium" level; and 0.19 and 0.029 for the "high" level, respectively. Total energy between 250 and 800 nm

wavelengths was kept at 5.9 ± 0.2 W/m². Visible light in the growth chamber was supplied by a combination of fluorescent tubes (Toshiba FLR80H W/A, Toshiba Ltd. Co., Tokyo, Japan), high intensity discharge lamps (Toshiba DR400/T(L), Toshiba Ltd. Co.) and tungsten lamps (RF 220V 200WH, National Ltd. Co., Osaka, Japan). Near-UV light with a large amount of UV-B and a small amount of UV-C (peaking around 310 nm) was supplied by Toshiba FL 20 SE fluorescent tubes (Toshiba Ltd. Co.).

When necessary, near-UV radiation was filtered through stainless steel-net filters to reduce the irradiance. Irradiance was measured at the top of the three-leaf seedlings with a spectroradiometer equipped with a multichannel detector (Hamamatsu Photonics Co., Hamamatsu, Japan) and CT-10 diffracting grating monochromator (Japan Spectroscopic Co., Tokyo, Japan) devised by Japan Spectroscopic Co. that allows the measurement of light irradiance ranging between 250 and 800 nm.

Growth of 9 plants was measured by plant height and fresh weight of the aboveground part (FW) of plant after irradiance treatment for 20 days. Total chlorophyll content in the 3rd leaf was determined according to the method of WINTERMANS and MOTS (1965). Absorbance was measured with a Shimadzu UV-300 spectrophotometer (Shimadzu Ltd. Co., Kyoto, Japan). The 3rd leaf was considered to be suitable for analyzing the influence of near-UV radiation on chlorophyll content, because it had been kept being exposed to experimental light treatments during the 20 day cultivation period.

Results

Fig. 1 shows the frequency distribution of the ratio (%) of the FW (sample/control) in 5 Asian ecotype cultivars and the Japanese lowland and upland cultivars. The FW of the sample and the control was derived from that of plants grown for 20 days under visible light with and without various irradiance levels of supplemental near-UV light, respectively.

When experimental plants were grown under the "low" irradiance level, a wide range in the frequency distribution was observed in every ecotype and group, but remarkable differences among ecotypes and groups were observed neither in the pattern of the distribution nor in the mean of the ratio of FW of sample/control (open columns in Fig. 1). Different sensitivities to the effects of near-UV radiation were involved in the same ecotype and in the same group: one type was promoted by near-UV radiation i.e. "resistance", while the other type was inhibited by near-UV radiation i.e. "sensitive". The proportion of cultivars resistant to the "low" irradiance level in individual ecotypes or groups differed: 79% for the *boro*; 69% for the *aus*; 68% for the *aman*; 57% for the *bulu* and 58% for the *tjereh*, respectively. As for the Japanese rice cultivars, 75% of the j.l.r. and 54% of the j.u.r. were resistant, respectively.

With an increase in the irradiance level of near-UV light to the "medium" level, the pattern of the frequency distribution of the ratio of FW of sample/control significantly shifted towards the lower values and the mean decreased markedly (black columns in Fig.1). However, it should be noted that j.l.r. maintained a mean of 83%, which was the highest value, and the *boro* ecotype showed 67%, while that the others showed a mean below 58%. Furthermore, the proportion of cultivars resistant to the "medium" irradiance level was 21%

for the j.l.r. and 14% for the *boro* ecotype, respectively, while that of others was below 4%.

With an increase in the irradiance level of near-UV light to the "high" level, the pattern of the frequency distribution of the ratio of FW of sample/control in all the ecotypes and groups was similar to that as seen in plants grown under the "medium" irradiance level,

Fig. 1 Frequency distribution of the ratio (%) of FW of the sample to that of the control. Open and black columns show the results of plants grown under the "low"- and "medium" irradiance levels of supplemental near-UV radiation, respectively. Ml and Mm are mean $\pm$ SD of ratio of FW in plants grown under the "low"- and "medium" near-UV radiation, respectively.

Fig. 2 Frequency distribution of the ratio (%) of plant height of the sample to that of the control. Open and black columns show the results of plants grown under the "low"- and "medium" irradiance levels of supplemental near-UV radiation, respectively. Ml and Mm are mean $\pm$ SD of ratio of plant height in plants grown under the "low"- and "medium" near-UV radiation, respectively.

except that the mean of each ecotype somewhat decreased (data not shown). Even in cultivars grown under the "high" irradiance level, 2 cultivars of j.l.r., and 1 cultivar of each of *boro*, *bulu* and *tjereh* exhibited resistance to the near-UV radiation.

Overall, the j.l.r. group and the *boro* ecotype appeared to be more resistant to the inhibitory effects of near-UV radiation.

Fig. 2 shows the distribution of the ratio of plant height of sample/control under the "low" irradiance level. The range of distribution of the ratio was narrower as compared with that of FW, and the mean was between 102 and 105%, which was very similar among each ecotype and group (open columns in Fig. 2). Both the promotion and the inhibition were caused by supplemental near-UV light.

Under the "medium" level, the mean of the j.l.r., the *boro* ecotype and the j.u.r. was 95%, 88% and 85%, respectively, while the others were between 81 and 79%. That is, the Japanese lowland rice group showed the most resistance to the near-UV radiation, which was followed by the *boro* ecotype.

The pattern of distribution of the ratio of plant height of sample/control under the "high" irradiance level was similar to that under the "medium" irradiance level, although the mean dropped.

Fig. 3 shows the distribution pattern of the ratio of chlorophyll content in the 3rd leaf of the sample/control.

Total chlorophyll content in all the ecotypes and groups grown under the "low" irradiance level decreased below the level of the control without exception. The degree of the reduction was intensified with the increase of the irradiance level of near-UV light to the "medium" level. The degree of 24% of the j.u.r. was the lowest, while that of the others was above 37%.

It was thus found that the reduction of chlorophyll content in the 3rd leaf did not correlate with the cultivar differences in resistance to the inhibitory effects of near-UV radiation on the increase in FW and plant height.

Discussion

We previously reported that there were cultivar differences among Japanese rice cultivars in resistance to the injuries caused by near-UV radiation, and a possibility that the rice cultivars having more resistance to near-UV radiation could be selected by examining the effect of various irradiance levels of near-UV radiation supplemented to visible radiation in a phytotron (KUMAGAI and SATO 1992). Consequently, we decided to examine the cultivar differences among 198 cultivars belonging to 5 Asian rice ecotypes and 2 Japanese rice groups in resistance to near-UV radiation.

As shown in Figs. 1 and 2, it was clear that the j.l.r. group and the *boro* ecotype were more resistant to the inhibitory effect of near-UV radiation on the fresh weight and plant height among ecotypes and groups tested. This means that the cultivar differences in resistance to the inhibitory effects of near-UV radiation would not simply be due to the difference in the geographical situation where rice cultivars had been cultivated. It was also found that the increase of FW in more than 2/3 of cultivars of the j.l.r. group and *boro* eco-

type and more than half of cultivars even in the j.u.r. group was promoted by the "low" irradiance level of supplemental near-UV radiation, although the increase of the irradiance level of supplemental near-UV radiation to the "medium" level decreased the number of cultivars promoted by near-UV radiation. It should be noted here that whether or not near-UV

radiation is in nature essential or useful for growth of rice plants is as yet unclear. This is a future problem.

On the other hand, it was doubted whether or not the inhibitory effects of the "low" irradiance level of near-UV radiation in individual cultivars similarly increased under the "medium" level. Fig. 4 shows the relationship between the ratio of the FW under the "low" irradiance level and the ratio of the FW under the "medium" irradiance level for the *boro* and *bulu* ecotypes and the j.l.r. group. It is clear that cultivars which showed stronger resistance to the "low" irradiance level did not necessarily show stronger resistance to the "medium" irradiance level. On the contrary, some cultivars showed stronger resistance to the "medium" irradiance level

Fig. 3 Frequency distribution of the ratio (%) of chlorophyll content in the 3rd leaf of the sample to that of the control.

Open and black columns show the results of plants grown under the "low"- and "medium" irradiance levels of supplemental near-UV radiation, respectively. Ml and Mm are mean $\pm$ SD of ratio of chlorophyll content in the 3rd leaf of plants grown under "low"- and "medium" near-UV radiation, respectively.

Fig. 4 Relationship between the ratio of FW of the sample/ control grown under the "low" irradiance level of near-UV radiation and the ratio of the sample/control grown under the "medium" irradiance level.

The result of the j.l.r group, *boro* and *bulu* ecotype was shown as (○), (●) and (◐), respectively.

than to the "low" irradiance level.

These findings indicate that rice plants might have different types of response to different irradiance levels of near-UV radiation: one was for the "low" irradiance level, the other being for the "medium" irradiance level. It was further suggested that the differences in resistance to the inhibitory effects of near-UV radiation among rice plants could relate to the difference between degrees of those two responses. Although the mechanism of resistance to near-UV radiation has not yet been elucidated, it was found that several cultivars (located in the upper right hand side in Fig. 4) would be helpful for breeding rice resistant to the inhibitory effects of near-UV radiation and for studying the mechanism of resistance to near-UV radiation.

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アジア栽培稲 (*Oryza sativa* L.) の生態型および日本水稻, 陸稲における近紫外光抵抗性に関する品種間差異

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我々は既に、日本型イネには近紫外光に対する抵抗性に明確な品種間差異が存在し、近紫外光による生長阻害(1), あるいはその傷害を回復する可視光の効果(2)を調べることによって、近紫外光に強い抵抗性を示す品種を探索できる可能性を示した(1992). 本研究では、(1)の結果に基づき、アジアの5生態型に属するイネと日本水稻および陸稲の合計198品種の生育に及ぼす近紫外光の影響を調査し、近紫外光に対し強い抵抗性を示す品種の検索を行った。同時に、近紫外光抵抗性の機構について若干の考察を行なった。

実験材料として、ベンガル地方の生態型 *aus*, *aman*, *boro* に属する48, 37, 14品種、インドネシアの生態型 *bulu*, *tjereh* に属する28, 31品種、日本水稻および陸稲29, 11品種を用いた。対照区と“弱”, “中”, “強”の3段階の異なった光強度の近紫外光(少量のUV-Cと多量のUV-Bを含む紫外光)の照射区を人工光型の環境調節実験室内に設け、各区で上記のイネを20日間生育させ、種々の光強度の近紫外光がイネ品種の生育に及ぼす影響を調査した。

対照区と各々の強度の近紫外光照射下で生育したイネの地上部新鮮重(FW)の割合(近紫外光区で生育したイネのFW/対照区で生育したイネのFW X 100%)に対応する各生態型あるいは品種群内の品種数の頻度分布、同様に草丈の割合(%)の頻度分布をFig. 1, 2に示したが、近紫外光の強度に関係なくいずれかの生態型、品種群もかなり広い分布を示した。近紫外光の強度を“弱”から“中”, “強”に高めると各品種の生長はより抑制されるので頻度分布は全体的に低い割合の方にシフトした。また、近紫外光(とくに“弱”強度の場合が顕著であるが)により新鮮重の増加が促進されるタイプ(近紫外光に強い抵抗性を示す品種)と阻害されるタイプ(感受性の高い品種)の2つのタイプの品種がどの生態型、品種群にも存在した。同様の結果は草丈においても認められた(Fig. 2)。注目されることは、Fig. 4に示されるように、“弱”強度の近紫外光に強い抵抗性を示した全ての品種が必ずしも“中”強度の近紫外光に強い抵抗性を示すのではなく、逆に“中”強度の近紫外光に強い抵抗性を示すが“弱”強度の紫外光には弱い抵抗性を示す品種が存在した。このことは“弱”, “中”の強度の近紫外光に対してイネは異なった反応機構を有することを暗示している。また、各生態型あるいは品種群内での“弱”強度の近紫外光に抵抗性を示した品種の割合は *boro*, *aus*, *aman*, *bulu* および *tjereh* ではそれぞれ79, 69, 68, 57 および58%であった。一方、日本水稻、陸稲では75 および54%であった。近紫外光強度を“中”にすると、抵抗性を示す品種数は減少し、*boro* および日本水稻ではそれぞれ21 および14%であったが、その他の生態型および品種群では4%以下であった(Fig. 1)。新鮮重や草丈などの生長に及ぼす近紫外光効果に対する抵抗性という点で見られた各生態型および品種群間差異は、クロロフィル含量面では認められなかった。(Fig. 3)。このように、アジアの5つのイネ生態型および2つの日本イネ品種群のうち、日本水稻および *boro* 生態型が相対的に近紫外光に強い抵抗性を示す品種群であり、強い抵抗性を示す品種がより多く含まれていること、また、近紫外光によって生育が促進される反応と阻害される反応がどの生態型、品種群においても存在することが認められた。さらに、このことと関連して、“弱”, “中”といった異なった近紫外光の強度に対して異なった反応が品種間において認められ、それらの反応量の差が近紫外光抵抗性に関する品種間差異に関係している可能性が示唆された。